A Comparison of Cloud Vendors

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***Abstract*—Technology has rapidly increased over the years which incentivizes companies to adapt to a new way to store data. Cloud computing and the services it provides allows users to access data from nearly anywhere if an internet connection is available. The idea of cloud computing allows service providers to move away from large data centers and offer all services via the world wide web[1]. Over the course of the last 20 years cloud computing has evolved into something truly incredible. The number of cloud service providers has continued to become larger, but some vendors might provide more features than others. Throughout this paper, we will discuss ten different cloud vendors and how they compare with one another. We will give a brief overview of each provider and discuss some of the advantages and disadvantages that pertain to each one.**

***Index Terms*—Cloud Computing, Cloud Service Providers, Cloud Vendors**

I. Introduction

Cloud computing is making a large impact on the way we interact in our daily lives so we should answer the question, what is cloud computing? Cloud computing allows vendors to deliver computing services such as databases, storage, networking, software, servers, analytics, and intelligence all over the internet[2]. Often, we hear people say, "What is the cloud?" and "Where is it?" The cloud is simply just services provided by a vendor over the internet so that data can be easily accessed by the customer from anywhere in a fast and efficient manner. The reason we are seeing a huge up tick in cloud computing is the benefits it delivers such as reduced cost, increased speed, use of a global scale, increased productivity, etc. In this paper, we will briefly dive into these benefits and explore why cloud computing is making such an impact.

Cloud computing is primarily made up of four different services, Infrastructure as a Service(IaaS), Platform as a Service(PaaS), Software as a Service(SaaS), and serverless. IaaS is a cloud computing service that offers compute, network, and storage resources to clients on a need basis[5]. PaaS is used primarily for applications and gives developers a platform that can be built on to[6]. This allows them to apply customizations to their applications so that their needs are met. SaaS is similar to PaaS however; SaaS uses the internet to deliver applications and most of these applications are run through a web browser[6]. Serverless computing gets rid of the responsibility for common infrastructure management tasks so that developers can focus on code execution on the cloud and not manage/maintain servers when deploying code. Later, we will describe these services in greater detail in order to help us fully understand their importance.

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Since cloud computing is becoming such a large industry this is creating a very competitive base for cloud vendors. Each vendor provides a set of services for customer to use on a pay-as-you-go basis[3]. During this paper, we are going to look at ten different cloud service providers:

1) Amazon Web Services (AWS)
2) Google Cloud Platform
3) Microsoft Azure
4) IBM Cloud Services
5) Oracle Cloud
6) Alibaba Cloud
7) HPE Cloud Services
8) ServerSpace
9) Openstack
10) DigitalOcean

The vendors will be researched and compared with one another to give us a better understanding of what each cloud provider has to offer. We will also try to determine which service vendor provides the most features.

II. Cloud Computing

As discussed previously, cloud computing is continuing to grow at a rapid pace. With this in mind, we must ask ourselves some very important questions. What are the different types and services of cloud computing and what are the benefits and drawbacks of cloud computing? During this section of the paper, we will go to into some of the specifics regarding cloud computing so that we can better understand cloud computing as a whole.

A. Types of Cloud Computing

Cloud computing is comprised of four main cloud types, the public cloud, the private cloud, the hybrid cloud and the community cloud. Each type has its own characteristics and restrictions that are followed. Below you will find descriptions of each type of cloud[11][12]:

- **Public Cloud:** The public cloud is the most commonly used cloud type. It is managed by a third party and is then deployed over the internet. Public clouds are

multitenancy and are designed to support multiple users. This means that users share things like hardware, storage, and networks with other users, but each user manages their own account.

- **Private Cloud:** The private cloud is limited to one company and can be set up either onsite or implemented by a third party host. Since the cloud is private this means that all resources are maintained over a private network and nothing is shared with other companies.
- **Hybrid Cloud:** The hybrid cloud is a mixture of both the public and the private cloud. Using a hybrid cloud allows businesses to utilize the best of both worlds. They will now have the ability to expand easily like a public cloud while also maintaining full control over their data.
- **Community Cloud:**The community cloud is an infrastructure that allows businesses with similar interests to share a cloud. This means that it can be managed privately or by a third party. This particular cloud would be designed to meet the specific needs of like businesses.

B. Types of Cloud Computing Services

In this section of the paper, we would like to discuss the different types of cloud computing services. As mentioned before there are four different services that need to be discussed (IaaS, PaaS, SaaS, and Serverless). Learning about the "as-a-Service" types is really a foundation to understanding the different features that each cloud vendor provides. Below you will find useful information regarding each type of cloud computing service[6][13]:

- **IaaS** IaaS is the most used service model due to its flexibility, high scalability, and the ability for customers to maintain complete control over their infrastructure. The IaaS model is basically your typical data center but based exclusively on the internet. IaaS is a fully virtual data center that allows customers to use and pay for only what they need. Customers that use IaaS are responsible for managing data, middleware, and OSes.
- **PaaS** PaaS is primarily used for developing and deploying apps. Unlike other models this service provides a platform for developing software and it is delivered over the internet. PaaS is really useful for programmers and developers because it allows users to fully develop, run, and mange all of their own content. One good thing about PaaS is that users do not have to worry about infrastructure, operating systems, or hardware maintenance.
- **SaaS** SaaS is very similar to PaaS however, a third-party provider manages the application you are using via the internet. Since this is managed by a third-party it is crucial that users pick the correct company for them due to lack of control. The nice thing about SaaS is that the applications that are provided run directly through a web browser. This means that companies do not have to worry about installations or software updates. Usually this sort of service is beneficial for small business that do not have the IT support to deploy an on system software.
- **Serverless** Serverless computing is not actually serverless. It requires server a to run code when developing and building applications. Severless computing removes the need for a managed infrastructure and the vendor will do all the scaling, provision, and manage all infrastructure that is needed. This allows programmers to focus more on the code than the infrastructure of the application.

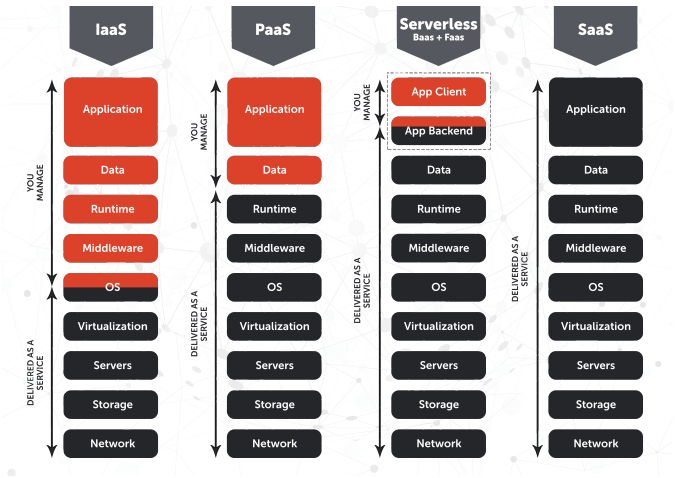

Fig. 1. Types of Services [14]

C. Benefits and Drawback of Cloud Computing

The reason cloud computing is growing so rapidly is because the benefits greatly outweigh the drawbacks. Companies are used to maintaining large data centers and the costs that come with them. In a data center, companies are responsible for purchasing all the hardware, the building that it is housed in, environmental stabilization systems, and much more just to maintain a stable system and database[7]. However, cloud computing is run strictly over the internet and companies do not need to maintain the physical aspects of a data center. Below we will discuss some of the main benefits to cloud computing[2][3][8]:

- **Cost:** The use of cloud computing greatly reduces the cost that service vendors will incur. The cloud works on a variable basis, so the cost is only accruing as the service is used. In data centers, the cost is never ending due to physical servers, constant electricity, and maintaining environmental conditions. Another place cost will be reduced is overhead. The service providers will still need people to maintain the cloud, but they will not need individuals to make repairs on physical hardware.
- **Speed & Flexibility:** The use of cloud computing allows for fast and flexible resources. This lets companies move at a much faster pace. Using the cloud allows them to remotely and quickly adjust the amount of storage or services they might need on a moment's notice! The agility and elasticity of cloud computing makes handling peak levels of business activity easier than ever.
- **Global Scale:** The use of a global scale permits users to access the cloud in new geographic regions and deploy

quickly. The global scale is closely related to cost and speed/flexibility because it gives companies the ability to scale the resources they need on demand.
- **Productivity:** Cloud computing increases productivity because service vendors do not need to worry about the data center management. Data center management takes a lot of time due to maintaining physical hardware, keeping software up to date, and other various server related tasks. This makes it easier for vendors to focus more on the services they are providing.
- **Reliability:** Cloud computing is overall more reliable because information can be backed up to various different places over the internet. If data centers crash, it increases the risk of data loss.

Furthermore, we should discuss some of the drawbacks. The drawbacks related to cloud computing are mostly related to the fact that it requires the internet for it to work. Below I am going to describe some of the drawbacks and why they can present a problem[9][10]:

- **Internet:** Cloud computing is based solely on the internet so if the internet is down or you are in an area where internet is limited then this could pose a huge problem. No internet means that individuals or companies will not be able to access the web services or data that they might need to maintain their business. In areas with limited access, we could see an overload on the servers that are available. In any case this would not be good!
- **Privacy & Security:** Although, service providers tend to follow strict privacy and security protocols our data is never completely safe once it is on the internet or stored in a server. Since cloud computing relies on the internet and virtual servers, we can say that our data might be vulnerable to data breaches.
- **Vendor Lock-In:** Cloud computing is still a relatively new technology and has not been perfected yet. One thing that could happen is vendor lock-in. Due to the lack of compatibility between vendors, companies may find it extremely difficult to switch between companies if needed. Even if you can switch companies you always risk the chance of data loss. This could make choosing a cloud vendor crucial because you do not want to have to change service providers.

III. Service Providers

Now that we developed a good understanding for what makes up cloud computing we can now start looking at all the different service providers. Throughout the rest of the paper, we are going to compare ten different cloud computing service providers. We will compare the compute services, virtual machines, serverless computing, storage services, object storage, database services, big data, analytics, data pipeline services, machine learning, artificial intelligence services, network services, and more! This will give use the enough knowledge to see just how far this technology has come and make an arguable guess as to which service we think is the best.

A. Compute Services

Compute services are a collection of services and functions that each service vendor provides. There are 5 main services that we looked for, virtual machines, auto-scaling, container image registry, container service and serverless computing. These services and functions are the key resources that make up the cloud. Each service and function provide us with a way to get rid of the big data centers and move toward a virtualized infrastructure. During our research we looked at 10 different cloud service providers and what kind of compute service that they offered. As seen in TABLE 1. We can see that almost all the providers have these 5 services that we were looking for. When researching HPE Cloud Services and ServerSpace Cloud we could not find any details in their documentation regarding serverless computing. Virtual machines were the start of cloud computing and then we moved towards containers since they are lighter weight and more portable. Now we are moving to serverless computing because it is based on functions and events. Containers are more difficult to scale due to the nature that each container runs on a single machine at a time and they continuously run regardless of idle[1][15]. Serverless computing provides users the advantage of only being charged when a function is executed. Serverless computing is a new as-a-Service model known as Function-as-a-Service (FaaS)[1][15]. This model is increasing productivity and reducing maintenance. Since serverless computing is up and coming it is not surprising that at least a couple service vendors have not jumped on board. AWS has been the leading cloud vendor for many years, and this is a direct reflection of the fact that they were one of the first providers around. Google Cloud, Microsoft Azure, Alibaba, IBM, and Orcle are all contenders for this leading role.

B. Virtual Machine Services

Next, we wanted to find some information related to virtual machines. We looked at hypervisors, auto scaling, vCPUs, Memory, storage, etc. Our goal was to get a good feel for the capabilities each cloud vendor provided when it came to the virtual machines. When looking at TABLES II and III we can see right away that AWS seems to the leading vendor when it comes to virtual machines. To us this was not a huge surprise since they have been the leading cloud vendor for several years now. AWS offers a service called EC2 which is a service that is designed to provide a secure and resizable compute capacity in the cloud over the web[3]. In fact, they provide 43 different sizes of virtual machines/instances[1]. While looking over these virtual machines/instances we found that they can support up to 256 vCPUs, 2400GB of memory, 16384(256/vCPU)GB attached storage and 320000GB of instance storage. Their platform uses a hypervisor called Nitro, has auto-scaling ability, allows custom VMs, has dedicated hosts, and supports bare metal. In comparison with other vendors, AWS was the most powerful. One other cloud vendor that stood out to us was ServerSpace. When browsing their website and the internet we discovered that we could not find

any information about CPUs, memory, or storage. This struck us as odd but we believe that they are just not as equipped as the other large companies are or they only provide that information when purchasing.

C. Serverless Computing Services

In addition, we would like to discuss serverless computing in more detail. As mentioned earlier, serverless computing is beginning to replace virtual machines and containers. With this in mind we wanted to get some information regarding the different features each provider has already implemented on their platform. Serverless computing allows users to run code without provisioning or managing servers[1][16]. This means that cloud providers will maintain server space, infrastructure, and the containers that the code is deployed in. If we look at TABLE IV we can see some information pertaining to serverless computing. We researched and compared each service provider and found that all providers support several programming languages and have automatic scaling. Each provider varies regarding HTTP invocation some use HTTP trigger and others use API gateway. The max execution time/ request varies among the different vendors. Google Cloud

Service Type	Virtual Machines	Auto-scaling	Container Image Registry	Container Service	Serverless Computing
Amazon Web Services	Amazon EC2	Amazon EC2 Auto-scaling	Amazon ECS Registry	Amazon ECS Service	AWS Lamda
Google Cloud Platform	Compute Engine	Google Auto-scaling MIGs	Container Registry	Container Engine	Cloud Functions
Microsoft Azure	Azure Virtual Machines	Azure Auto-scale	Azure Container Registry	Azure Container Instances	Azure Functions
IBM Cloud Services	Virtual Servers VPC	IBM Auto-scaling	Container Registry	Kubernetes Service	IBM Functions
Oracle Cloud	Oracle VMs	Oracle Auto-scaling	Container Registry	Oracle Container Engin	Oracle Functions
Alibaba Cloud	ECS & EBM	Auto Scaling	Container Registry	Container Service ACK	Function Compute 2.0
HPE Cloud Services	Greenlake	Bluedata	Container Registry	Ezmeral Container Service	-
ServerSpace	Cloud Servers	Agile Scaling	Container Registry	Serverspace ACK	-
Openstack	Nova	Heat	Docker	Zun	Qinling
DigitalOcean	Droplets	Cluster Auto Scaler	DigitalOcean Container Registry	DigitalOcean Containers	OpenFaaS

TABLE I
COMPUTE SERVICES

Virtual Machines & Features	Service	Hypervisor	Auto Scale Ability	Max vCPUs	Max Memory (GB)
Amazon Web Services	AWS EC2	Nitro	✓	256 (EC2)	2400
Google Cloud Platform	Compute Engine	KVM	✓	224 (N2D)[3]	1792 (8/vCPU)
Microsoft Azure	Azure Virtual Machines	Azure Hypervisor	✓	32(G5)	448 (G5)
IBM Cloud Services	Virtual Servers VPC	Hyper-V	✓	105 (Enterprise)	840
Oracle Cloud	Oracle VMs	KVM	✓	64	1024
Alibaba Cloud	ECS & EBM	Alibaba Cloud Hypervisor	✓	256	1024
HPE Cloud Services	Greenlake	VMware or Red Hat	✓	241	829
ServerSpace	Cloud Servers	Bhyve Hypervisor	✓	-	-
Openstack	Nova	HyperV, Xen, KVM, etc	✓	288	4000
DigitalOcean	Droplets	KVM	✓	32	256

TABLE II
VIRTUAL MACHINES PART 1

Virtual Machines & Features	Max Attached Storage(GB)	Max Instance Storage (GB)	Custom VMs	Dedicated Hosts	Bare Metal
Amazon Web Services	16384 (256/vCPU)	320000	✓	✓	✓
Google Cloud Platform	14336 (224/vCPU)	257000	✓	✓	✓
Microsoft Azure	6598(G5)	32000	✓	✓	✓
IBM Cloud Services	12288	-	✓	✓	✓
Oracle Cloud	15488	32000	✓	✓	✓
Alibaba Cloud	16384	100000	✓	✓	✓
HPE Cloud Services	23998	-	✓	✓	✓
ServerSpace	-	-	-	✓	-
Openstack	18432	-	-	✓	✓
DigitalOcean	16384	-	✓	-	-

TABLE III
VIRTUAL MACHINES PART 2

Serverless Computing Services & Features	Service	Supported Languages	Max Execution Time / Request	Scalability	HTTP Invocation	Log Management	Concurrent Executions
Amazon Web Services	AWS Lamda	Java, Go, PowerShell, Node.js, Python, Ruby, C#	15 min	Automatic Scaling	API Gateway	AWS Log	1000 Instances
Google Cloud Platform	Cloud Functions	Java, .Net, Go, Python, Node.js	Unlimited	Automatic Scaling	HTTP Trigger	Cloud Logging	250 Instances
Microsoft Azure	Azure Functions	C#, Java, F, Javascript, PoweShell, Python, TypeScript	10 min	Automatic Scaling	HTTP Triggered	Azure Monitor Logs	250 Instances
IBM Cloud Services	IMB Functions	Node.js, Swift, Java, Ruby, Python	10 min	Automatic Scaling	API Gateway	IMB Log Analysis	1000 Instances
Oracle Cloud	Oracle Functions	Java, Node.js, Python, Go, SQL	5 min	Automatic Scaling	API Gateway	Log Analytics	128 Instances
Alibaba Cloud	Function Compute 2.0	Node.js, Python, Java, C#, C++, Ruby, Go, etc	10 min	Automatic Scaling		HTTP Triggered	100
HPE Cloud Services	-	Java, Ruby, Node.js, Python, Go, etc	-	Auto Scaling	HTTP Triggered	HPE OneView	-
ServerSpace	-	JavaScript, PHP, SQL, HTML	-	Agile Scaling	API Gateway	-	-
Openstack	Nova	Bash, Java, Python	5 min	Automatic Scaling	API Gateway	Logging	10
DigitalOcean	OpenFaaS	Node.js, Python, Go, PHP,Ruby, etc	Unlimited	Automatic Scaling	API Gateway	Logging	100

TABLE IV
SERVERLESS COMPUTING

and Digital Ocean both have unlimited execution time and all the rest fluctuate between 5 and 15 minutes. The number of concurrent executions topped out at 1000 instances. AWS and IBM were the leaders in this area. Overall, we did not see that one cloud vendor went above and beyond the rest. They were all pretty comparable.

D. Storage Services

Following serverless computing, we explored storage services. We wanted to see if each cloud vendor provided object storage, virtual machine disk (block) storage, long term cold storage, and file storage. By looking at TABLE V, we can conclude that almost all providers provide these services. ServerSpace came up short again and does not provide long term cold storage or file storage to our knowledge. We searched their website and came up empty.

First, we investigated the object storage that each service vendor provides. Object Storage is a form of storing data in the form of an object. These objects are not like file storage where the data is stored in a file hierarchy[17]. The object will be made up of metadata and the data you wish to store[17].

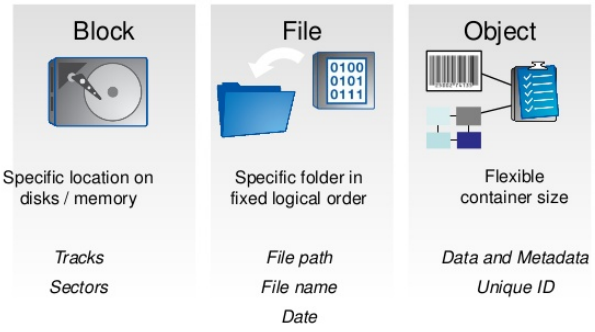

Fig. 2. Storage Types

Service Type	Object Storage	Virtual Machine Disk (Block) Storage	Long Term Cold Storage	File Storage
Amazon Web Services	Cloud Object Storage	Amazon Elastic Block Store	Cloud Data Archiving	Amazon Elastic File System
Google Cloud Platform	Cloud Storage	Cloud Persistent Disks	Archival Cloud Storage	File Store
Microsoft Azure	Azure Storage	Blob Storage	Azure Archive Storage	Azure Files
IBM Cloud Services	Cloud Object Storage	Cloud Block Storage	Cold Vault	File Storage
Oracle Cloud	Object Storage	Block Volume	Archive Storage	File Storage
Alibaba Cloud	OSS	Block Storage	Archive Solution	Files Storage NAS
HPE Cloud Services	Object Storage	Data Storage	Data Protection Solutions	File Storage
ServerSpace	S3 and Swift	Block Storage	-	-
Openstack	Swift	Cinder	Swift	Manila
DigitalOcean	Spaces	Block Storage	Spaces	Spaces

TABLE V
STORAGE SERVICES

Object Store	Store Cost (cents/GB/mo)	Availability (%)	Regions
Amazon Web Services			
S3 Standard	$0.024	99.9%	23 Regions:USA(6), Africa(1), Asia(7), Canada(1), Europe(6), Middle East(1), South America(1)
S3 Intelligent Automatic cost savings	$0.0025-$0.023	99.9%	23 Regions:USA(6), Africa(1), Asia(7), Canada(1), Europe(6), Middle East(1), South America(1)
S3 One Zone	$0.01	99.9%	23 Regions:USA(6), Africa(1), Asia(7), Canada(1), Europe(6), Middle East(1), South America(1)
S3 Glacier	$0.004	99.9%	23 Regions:USA(6), Africa(1), Asia(7), Canada(1), Europe(6), Middle East(1), South America(1)
S3 Glacier Deep Archive	$0.00099	99.9%	23 Regions:USA(6), Africa(1), Asia(7), Canada(1), Europe(6), Middle East(1), South America(1)
Google Cloud Platform			
Standard Storage	$0.020	99.0%	31 Regions:USA(9), Australia(1), Asia(10), Europe(8), Middle East(1), South America(1), North America(1)
Nearline Storage	$0.010	99.0%	31 Regions:USA(9), Australia(1), Asia(10), Europe(8), Middle East(1), South America(1), North America(1)
Coldline Storage	$0.004	99.0%	31 Regions:USA(9), Australia(1), Asia(10), Europe(8), Middle East(1), South America(1), North America(1)
Archive Storage	$0.0012	99.0%	31 Regions:USA(9), Australia(1), Asia(10), Europe(8), Middle East(1), South America(1), North America(1)
Microsoft Azure			
Block Blobs	$0.00081	99.9%	23 Regions:USA(10), Brazil(1), Canada(2), Chile(1), Mexico(1), USA GOV(8)
Azure Data Lake Storage	$0.00081	99.9%	23 Regions:USA(10), Brazil(1), Canada(2), Chile(1), Mexico(1), USA GOV(8)
Managed Disks	$1.54	99.9%	23 Regions:USA(10), Brazil(1), Canada(2), Chile(1), Mexico(1), USA GOV(8)
Files	$0.058	99.9%	23 Regions:USA(10), Brazil(1), Canada(2), Chile(1), Mexico(1), USA GOV(8)
IBM Cloud Services			
Smart Tier - Hot	$0.0227	-	21 Regions:USA(4), Asia Pacific(7), Europe(6), North America(3), South America(1)
Smart Tier - Cool	$0.0144	-	21 Regions:USA(4), Asia Pacific(7), Europe(6), North America(3), South America(1)
Smart Tier - Cold	$0.0090	-	21 Regions:USA(4), Asia Pacific(7), Europe(6), North America(3), South America(1)
Standard	$0.0238	-	21 Regions:USA(4), Asia Pacific(7), Europe(6), North America(3), South America(1)
Vault	$0.0144	-	21 Regions:USA(4), Asia Pacific(7), Europe(6), North America(3), South America(1)
Cold Vault	$0.0072	-	21 Regions:USA(4), Asia Pacific(7), Europe(6), North America(3), South America(1)
Oracle Cloud			
Infrequent Access	$0.01	99.0%	22 Regions:USA(3), Australia(2), Brazil(1), Canada(2), Chile(1), Europe(5), Japan(2), India(2), Saudi Arabia(1), South Korea(2), Dubai(1)
Infrequent Access - Retrieval	$0.01	99.0%	22 Regions:USA(3), Australia(2), Brazil(1), Canada(2), Chile(1), Europe(5), Japan(2), India(2), Saudi Arabia(1), South Korea(2), Dubai(1)
Standard	$0.0255	99.0%	22 Regions:USA(3), Australia(2), Brazil(1), Canada(2), Chile(1), Europe(5), Japan(2), India(2), Saudi Arabia(1), South Korea(2), Dubai(1)
Requests	$0.0034	99.0%	22 Regions:USA(3), Australia(2), Brazil(1), Canada(2), Chile(1), Europe(5), Japan(2), India(2), Saudi Arabia(1), South Korea(2), Dubai(1)
Alibaba Cloud			
Standard	$0.0185	99.0%	22 Regions:USA(2), Australia(1), Brazil(1), Malaysia(1), China(10), Europe(2), Japan(2), India(1), Indonesia(1), Dubai(1)
Infrequent Access	0$0.0100	99.0%	22 Regions:USA(2), Australia(1), Brazil(1), Malaysia(1), China(10), Europe(2), Japan(2), India(1), Indonesia(1), Dubai(1)
Archive	0.0036	99.0%	22 Regions:USA(2), Australia(1), Brazil(1), Malaysia(1), China(10), Europe(2), Japan(2), India(1), Indonesia(1), Dubai(1)
HPE Cloud Services			
HPE Cloud Services	No Pricing Found	-	-
ServerSpace			
ServerSpace	No Pricing Found	-	-
Openstack			
Openstack	No Pricing Found	-	-
DigitalOcean			
Spaces Object Storage	$0.02	99.0%	13 Regions:USA(6), Japan(1), Europe(4), Canada(1), India(1)

TABLE VI
OBJECT STORAGE

It will then be assigned a custom identifier so that the data can be easily accessed. Object storage is usually priced on a pay as you go basis and is highly scalable. We looked at each provider and tried to determine the pricing that each one charged for various types of object storage. We also researched regions and the availability rating. This is important because the data you are storing should be able to get accessed from anywhere. If we look closely at TABLE VI, we can see that many of the services providers have various different types of object storage all at different rates. Some of the vendors even had services that were free for a very small amount of storage which we did not include in the table. Typically, an archive storage or cold storage is going to cost a lot less than a standard or hot storage. We compared each vendor, and it seems as if all the pricing is pretty comparable. Most of the vendors have multiple regions of availability which averaged at about 99.0%.

Secondly, we wanted to find some information regarding block storage among the ten cloud vendors. Block storage is similar to object storage where the data is broken down into pieces. These pieces or volumes are called blocks. Each block is then assigned a unique identifier and stored on Storage Area Networks or in a cloud-based environment[5]. Block storage can be scaled but is much more limited than object storage. We will not go into extensive detail regarding each vendor and the block storage services they provide however, we do believe that just like in many other cases throughout this paper AWS, Google Cloud, Azure, IBM and Oracle will be the leading forces. Each one of these vendor seems to be the most developed overall.

Last but not least, let's talk a little bit about file storage. File storage is where data is taken and then stored in a file on a network attached storage (NAS) device or on hard drives. Instead of objects or blocks, file storage takes the data stores in a file and then it goes into a folder[5]. One major drawback of this type of storage is that once you accumulate a large number of files the retrieval of data could become difficult. If we look back at TABLE V we will notice that all but one vendor has file storage. ServerSpace seems to be less evolved than the rest of the companies for many reasons. Again, we will not go into detail about each vendor but the most of them seem to be well versed in file storage.

E. Database Services

Furthermore, we would like to talk about some of the database services that cloud vendors provide. The first database service we are going to talk about is relational databases. The relational database system is made up of tables that have rows and columns. The data is placed in tables based on pre-defined relationships so that it can be appropriately stored and accessed easily[3]. There are four main parts to a relational database[3]:

1) **Structured Query Language(SQL) -** SQL is the language that is used to communicate with a relational database. It can be used to edit or retrieve information from the tables. SQL allows us to do everything within the database and can be considered the manager of the database.
2) **Transactions -** In a relational database, transactions are SQL statements that are executed within the database. When the statements are executed all statements must complete successfully or the transaction will be cancelled. Every transaction is an independent unit.
3) **Atomic, Consistent, Isolated, Durable (ACID) Compliant -** This key feature to relational databases ensures that all data that is implemented into the database follows strict rules. Atomicity ensures that transactions in the database are successfully executed and if they are then the the whole transaction will be forced to fail. Consistency makes sure that the data enters the system in a constructive manner. It requires that all data follows all defined rules and restrictions. Isolation ensures that all incoming data or transaction is independent of all other transactions. Durability refers to the process of ensuring that each change made to a transaction is permanent once it has been successfully completed.
4) **Data Integrity -** Data integrity is in place to make sure that all data is reliable and accurate. The process that is used ensures that all data meets a given set of constraints. These constraints could be 'unique' constraints, 'Default' constraints, 'Not NULL' constraints, etc.

If we look at TABLE VII, we can see the different relational databases that each cloud vendor provides. Some of the different vendors have more than one which means that they could be tailored to specific needs. One thing that we did find interesting is that ServerSpace did not have any available information regarding their relational databases.

Service Type	Relational Database Management	Non Relational Database Management	In-Memory Data Store	Cloud Extract, Transform, Load(ETL)
Amazon Web Services	RDS & Aurora	DocumentDB	ElastiCache	Data Pipeline
Google Cloud Platform	Bare Metal Solution, Could SQL & Cloud Spanner	Cloud Bigtable & Firestore	Memorystore	Cloud Data Fusion
Microsoft Azure	Azure SQL Database	Azure Cosmos DB	Azure Cache for Redis	Azure Data Factory
IBM Cloud Services	IBM Db2, PostgreSQL	MongoDB	IBM solidDB	IBM DataStage
Oracle Cloud	Relational Database Management System (RDBMS)	Oracle NoSQL Database	Oracle Database In-Memory	Oracle ETL
Alibaba Cloud	Distribute Relational Database Service(DRDS)	ApsaraDB for Redis	ApsaraDB for Memcache	Data Integration
HPE Cloud Services	HPE Storage	HPE NoSQL	In-Memory Computing	SteamSets
ServerSpace	-	-	-	-
Openstack	Trove	Trove	Zaqar Redis	Openstack API ETL
DigitalOcean	MySQL & PostgreSQL	MongoDB	MemcahedDB Redis	DigitalOcean ETL

TABLE VII
DATABASE SERVICES

Now let's discuss non-relational databases. Non-relational databases are different from relational databases because they do not store data in tables. Non-relational databases follow a different storage model and are usually tailored to specific requirements that pertains to the data that is being stored[18]. In relational databases we discussed how SQL is the primary language that is used to communicate with the database but in non-relational databases the language they use is referred to as NoSQL. The reason it is called NoSQL is because they create databases that are tailored to specific data which allows them to use other languages[18]. However, this does not necessarily mean that non-relational databases do not support SQL queries[18]. If we look at TABLE VII again, we can see the different databases that each vendor supports.

Next, we will discuss in-memory databases. In-memory databases are a type of database that stores data in main memory[3]. The reason we would want to store the database in main memory is for very quick access. The response time main memory is going to much faster than the other databases we have discussed previously. One thing we need to keep in mind is that even though we can access the data faster this also make the data susceptible to loss[3]. In-memory databases can keep a log of the data they have processed in order to keep it available on a disk[3]. Refer to TABLE VII to see the different in-memory databases that the vendors support.

Finally, we want to discuss one last database service which is Extract, Transform, Load (ETL). ETL is a database that pulls data from multiple sources extracts it, transforms it, and loads it so that it can be combined and stored in a data warehouse[19]. Although data warehouses are less prevalent now a day, ETL is still being used regularly in cloud computing. The reason ETL is still so prevalent is because it provides users with the ability gain deep historical context, which allows them to view the data in a consolidated form, improves productivity, and improves the accuracy of data and audit capabilities[20]. This helps business bring the data up into a repository for better analysis. When looking at TABLE VII we can see that all providers except ServerSpace use ETL.

F. Big Data, Analytics, and Data Pipe lining Services

Big data, analytics, and data pipe-lining services will always be a part of the way we interact with data. In this section of the paper, we are going to discuss these topics and provide the names of the services each cloud vendor uses. Let's begin with big data. Big data is exactly what it sounds like, it is a very large volume of data. Although this is the technical definition, big data by itself is not the important key here. Big data is often analyzed and used by large business so that they can make informed decisions about business transactions[19]. If we use big data in conjunction with analytics this can help businesses to improve technical issues, reduce costs, reduce risk, and stop fraudulent behavior within the business[19]. Analytics uses math and data to help discover new outcomes, new relationships, or even automate the decision-making process within a business[19]. This idea leads us right into data pipe-lining. Data pipe-lining allows us to automate the movement and transformation of data[3]. The data is taken from the source and then it is moved to the destination so that businesses can analyze it.

During our research, we looked to see if businesses offered services like hadoop, data warehousing, data streaming, and data queuing. These features help us to build the foundation for big data, analytics, and data pipe-lining. Hadoop is what helps us process and store big data. The data can be either structured on unstructured. Then the data is processed and stored in a commodity server as a cluster[19]. People often think that Hadoop is used to replace the data warehousing, but this is not the case[21]. In fact, it is used in conjunction with relational database systems[21]. Data warehouses are commonly used to store and organize the large amounts of data that companies have. As the data comes into the warehouse usually data streaming and queuing are used to help us continuously generate data from consumers or business transactions. Data streaming ensures that the data is processed in a sequential and incremental manner so that it can be analyzed appropriately[3]. Once the data has gone through this process, it can then be used by businesses to discover and to improve things such a business transactions. After this the data can be released from the data queue. The data queue is particularly useful because it holds the data for a period of time so that it can help to decouple heavyweight processing, buffer, and smooth out spikes in a workload[3]. TABLE VIII shows the names of the services that each vendor has. We could not find an information on ServerSpace and the services they provide in this area. Please feel free to look up any of the services to find further details on these vendor exclusive services.

Service Type	Hadoop	Data Warehousing	Data Streaming	Data Queuing
Amazon Web Services	AWS EMR	AWS Redshift	AWS Kinesis	AWS SQS
Google Cloud Platform	Dataproc	BigQuery	Cloud Dataflow	Cloud Tasks & Pub/Sub
Microsoft Azure	Azure HDInsight	Azure SQL Data Warehouse	Azure Stream Analytics	Queue Storage
IBM Cloud Services	Apache Hadoop	IBM DB2 Warehouse	IBM Streams	IBM Data Queues
Oracle Cloud	Orcle Hadoop	Orcle Autonomous Data Warehouse	Orcle Streaming Service	Orcle Datbase Advanced Queuing
Alibaba Cloud	E-MapReduce Service	MaxCompute	Realtime Compute for Apache Flink	AlibabaMQ for Apache RocketMQ
HPE Cloud Services	GreenLake Hadoop	HPE Cloud Volumes	HPE Moonshot	HPE NonStop Message Queue(NSMQ)
ServerSpace	-	-	-	-
Openstack	Sahara	Apache Hive	Sahara Storm	RabbitMQ, ZeroMQ, Qpid
DigitalOcean	Apache Hadoop	-	Big Data	RabbitMQ

TABLE VIII
BIG DATA, ANALYTICS, AND DATA PIPELINE SERVICES

Service type	Machine Learning	Language Processing & Speech Recognition AIs	Image Recognition
Amazon Web Services	AWS Machine Learning	AWS Comprehend & AWS Transcribe & AWS Polly	Rekognition
Google Cloud Platform	AI Platform	Cloud Natural Language & Speech-to-Text	Vision AI
Microsoft Azure	Azure Machine Learning	Text Analytics & Cognitive Speech Services	Computer Vision
IBM Cloud Services	Watson Machine Learning	Natural Language API & Watson Speech to Text (STT)	Visual Recognition
Oracle Cloud	Oracle Machine Learning	Orcle Natural Language Processing & Orcle Voice	Netra
Alibaba Cloud	Machine Learning Platform for AI	Machine Translation & Intelligent Speech Interaction	Image Search
HPE Cloud Services	Machine Learning Solutions	HPE'S NLP & HPE's STT	HPE Image Classification
ServerSpace	-	-	-
Openstack	Gyan	-	Image Service
DigitalOcean	DigitalOcean Machine Learning	Natural Language Toolkit	Deadletter

TABLE IX
MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE SERVICES

Networking Services	Virtual Networking	DNS Services	Private Connectivity	Content Delivery Network	Load Balancing
Amazon Web Services	AWS Virtual Private Cloud(VPC)	Route 53	PrivateLink	CloudFront	Elastic Load Balancer
Google Cloud Platform	Cloud VPC	Cloud DNS	Private Connect Service	Cloud CDN	Load Balancing
Microsoft Azure	Azure Virtual Network	Azure DNS	Azure Private Link	Azure CDN	Azure Load Balancer
IBM Cloud Services	IBM Cloud VPC	IBM Cloud DNS	IBM Direct Link	IBM CDN	IBM cloud Load Balancer
Oracle Cloud	Oracle Virtual Cloud Networks (VCN)	Oracle DNS	Orcle FastConnect	Oracle CDN	Orcle Load Balancer
Alibaba Cloud	Alibaba VPC	Alibaba Cloud DNS	Alibaba Express Connect	Cloud CDN	Cloud Server Load Balance(SLB)
HPE Cloud Services	Distributed Cloud Networking Services	HPE DNS	Private Cloud Solutions	HPE CDN	HPE Load Balancer
ServerSpace	ServerSpace VPC	Cloud DNS	Virtual Private Cloud	ServerSpace CDN	-
Openstack	Neutron	Openstack DNS Service	Virtual Private Network-as-a-Service(VPNaaS)	Poppy	Load Balancer-as-a-Service(LBaaS)
DigitalOcean	DigitalOcean VPC	DigitalOcean DNS	VPC	Spaces CDN	DigitalOcean Load Balancer

TABLE X
NETWORKING SERVICES

G. Machine Learning and Artificial Intelligence Services

Machine learning and artificial intelligence are growing at a rapid pace. Today we can use services such as language processing, speech recognition, and image recognition to improve the way we interact in our daily lives. During our research we found that many of the vendors are keeping up with the times and have implemented such services within their platforms. Since AWS was one of the first vendors to launch their cloud computing services and are the most advanced when it comes to services offered. When researching services, we found that Openstack does not provide a service related to language process or speech recognition. ServerSpace again continues to fall behind with the advancements in technology and does not appear to offer any of the services mentions. Refer to TABLE IX to find out the names of each service.

H. Network Services

Lastly, we would like to touch on the network services that each cloud vendor has. Lets start with virtual networking. Virtual networking is a service that allows computers, virtual machines, and virtual servers to communicate with one another[22]. Using virtual networks give us the ability to connect our computers and servers over a network so they can communicate remotely for nearly anywhere. A content delivery network(CDN) helps us to establish that. CDN is a set of servers located around the world that help us to deliver content over the internet in a fast and efficient manner. Virtual networks and CDNs give us the ability to make changes to servers or devices which increases productivity. The use of virtual network software enables our ability to turn on and off this virtual network[22]. Virtual machines apply this idea, and we can use this to set up virtual adapter so that our devices can communicate with one another[22]. This is where DNS services come in. DNS services allow devices on a network to find each other using IP addresses. It is similar to a phone book but internet based[23]. In addition to virtual networking and DNS services, we often need to set up private connectivity or a private network. We can use DNS and private IP addresses to do just that. In the event that the network becomes congested we will need to use a load balancer to help evenly distribute the number of connections on a given network or server. The load balancer will sit between devices and servers so that it can evenly distribute connections. While doing research about the ten different cloud vendors we found that all providers offer these services. If you look at TABLE X we can see that ServerSpace did lack in load balancing but this might just be because they don't provide documentation on their website about it.

IV. CONCLUSION

. After researching ten different cloud vendors we found that AWS, Google Cloud Platform, Microsoft Azure, and IBM are definitely the leading cloud vendors on the market. One of our sources "A Comparative Taxonomy and Survey of Public Cloud Infrastructure Vendors" by Dimitrios Sikerdis, Loannis Papapanagiotou, Bhaskar Prasad Rimal, and Michael Devetsikiotis limits research to these four providers which we believe is because they have continuously been classified as the best cloud service vendors. From the services provided to the documentation and underlying specifications that each one of these providers has makes it hard for other small vendors to compete. Other vendors such as Oracle, Alibaba, and DigitalOcean are definitely mid-grade vendors and as time goes on we can see them continuing to grow to a place where they can compete. ServerSpace was by far the most underdeveloped vendor that we came across. They lacked in

many areas and we hope to see them improve in the future. Our goal was to provide a comparison of each vendor which I believe we captured however, due to lack of time we were not able to go into as much detail regarding each vendor as we would have liked.

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